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Mapping giant salvinia with satellite imagery and image analysis

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Abstract QuickBird multispectral satellite imagery was evaluated for distinguishing giant salvinia (*Salvinia molesta* Mitchell) in a large reservoir in east Texas. The imagery had four bands (blue, green, red, and near-infrared) and contained 11-bit data. Color-infrared (green, red, and near-infrared bands), normal color (blue, green and red bands), and four-band composite (blue, green, red, and near-infrared bands) images were studied. Unsupervised image analysis was used to classify the imagery. Accuracy assessments performed on the classification maps of the three composite images had producer's and user's accuracies for giant salvinia ranging from 87.8 to 93.5%. Color-infrared, normal color, and four-band satellite imagery were excellent for distinguishing giant salvinia in a complex field habitat.

Keywords QuickBird satellite imagery · Color-infrared imagery · Normal color imagery · Four-band composite imagery · Unsupervised image analysis · Accuracy assessment · *Salvinia molesta*

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Introduction

Giant salvinia is a floating aquatic fern native to Brazil that has spread to many other freshwaters of the world (Oliver 1993). It has been reported from more than 20 countries in tropical and subtropical regions (Mitchell 1976; Room et al. 1981; Oliver 1993). Giant salvinia ranks second behind waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] on the nuisance weed list (Barrett 1989). The plant develops dense mats that interfere with rice cultivation, clog fishing nets, and disrupt access to water by humans, livestock, and wildlife (Mitchell and Gopal 1991; Creigh 1991). Giant salvinia damages ecosystems by overgrowing and replacing native plants that provide food and habitat for wildlife. It also blocks out sunlight and decreases oxygen concentrations to the detriment of fish and other aquatic species (Cook 1990; Mitchell and Gopal 1991). This weed has been reported from all of the coastal southern United States from Texas to Virginia, as well as California, Arizona, and Hawaii (Owens et al. 2004; USGS 2004). In 1998, a major infestation of giant salvinia was found in Toledo Bend Reservoir in east Texas (Chilton 1998). It has since spread to other reservoirs, rivers, and ponds in Texas (Owens et al. 2004; USGS 2004).

Everitt et al. (2002) described the light reflectance characteristics of giant salvinia and used color-infrared aerial photography coupled with image analysis techniques to distinguish and map this weed in southeast Texas. In the past few years, high spatial resolution (2.4–4 m) satellite imagery from commercial companies has become available for remote sensing applications. The Space Imaging IKONOS and DigitalGlobe QuickBird satellites enable observations in visible and near-infrared wavebands. The high resolution of these satellites has considerable potential for assessing natural resources. Multispectral IKONOS data have been used successfully to classify wetland habitat types (Dechka et al. 2002) and to distinguish invasive aquatic weeds (Jakubauskas et al. 2002). Wang et al. (2004) used IKONOS and QuickBird multispectral imagery for mapping mangrove vegetation in coastal areas. QuickBird multispectral imagery has also proven useful for distinguishing among wetland vegetation (Everitt et al. 2004), detecting invasive weeds (Weber et al. 2006), and mapping rangeland cover types in riparian areas (Everitt et al. 2005). The objective of this study was to evaluate QuickBird satellite imagery and image analysis techniques for distinguishing and mapping giant salvinia on Toledo Bend Reservoir in east Texas.

Materials and methods

The specific study site was located on Siepe Bayou (31° 43N 93° 51W) on the west side of Toledo Bend Reservoir near the small community of Huxley, Texas. This site was selected because it had a large infestation of giant salvinia. QuickBird multispectral and panchromatic satellite imagery, followed by computer image analysis and accuracy assessments of image analysis maps were used for this study.

Siepe Bayou is surrounded on the west, north, and south sides by forested vegetation composed of hardwoods and conifers. Common woody species included several species of pines (*Pinus* spp.), oaks (*Quercus* spp.), and bald cypress [*Taxodium distichum* (L.) Rich.]. Giant salvinia was the dominant aquatic plant species on the study site. Alligator weed [*Alternanthera philoxeroides* (Mart.) Griseb.] was the second most common aquatic species. Other common aquatic species included American lotus [*Nelumbo lutea* (Willd.) Pers.], parrotfeather [*Myriophyllum aquaticum* (Vell.) Verd.], waterhyacinth, pennywort (*Hydrocotyle ranunculoides* L. F.), burhead [*Echinodorus rostratus* (Nutt.) Engelm. Ex Gray], smartweed (*Polygonum pennsylvanicum* L.), water primrose [*Ludwigia peploides* (Kunth.) Raven], and torpedograss (*Panicum repens L.).*

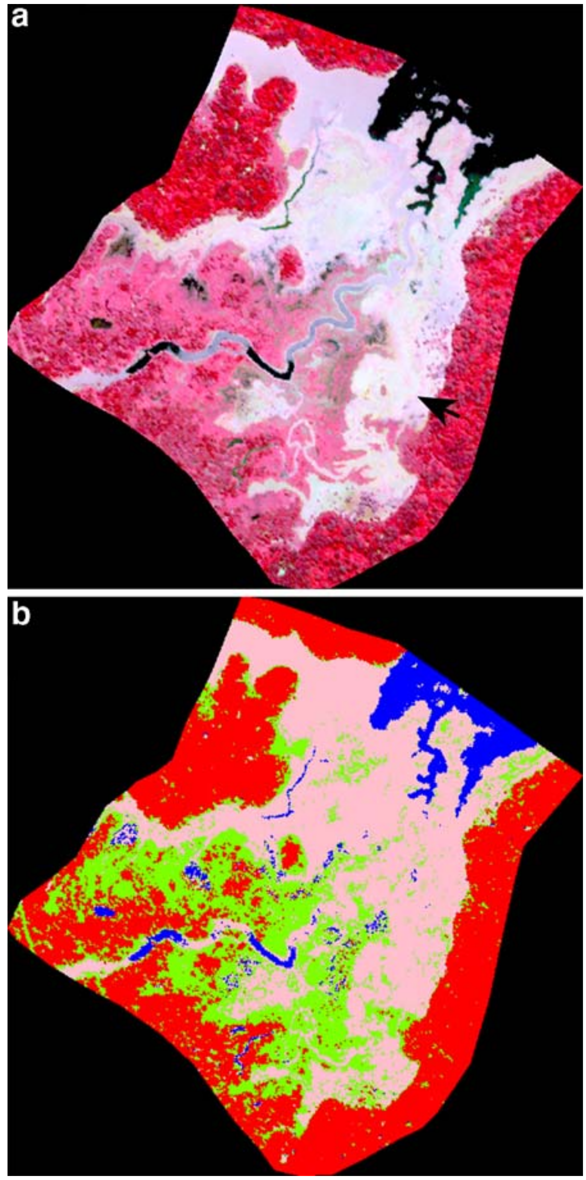

Fig. 1 QuickBird color-infrared satellite image (**a**) of a giant salvinia infestation on Toledo Bend Reservoir in east Texas. The *arrow* points to giant salvinia. The image was acquired June 23, 2006. Unsupervised classification map (**b**) of the satellite image. Color codes for the surface types on the classification map are: *pink*, giant salvinia; *red*, mixed woody vegetation; *green*, mixed aquatic vegetation; and *blue*, water

Multispectral (2.4 m spatial resolution) and panchromatic (0.6 m spatial resolution) imagery of the study site was acquired 23 June 2006 by the Quick-

Table 1 An error matrix for the unsupervised classification data and ground data for the color-infrared QuickBird satellite image of the giant salvinia study site on Toledo Bend Reservoir in east Texas

Classified category	Actual category				Total	User's accuracy (%)
	Giant salvinia	Mixed aquatic	Woody	Water		
Giant salvinia	46	3	1	0	50	92.0
Mixed aquatic[a]	2	26	2	0	30	86.7
Woody[b]	0	2	55	0	57	96.5
Water	1	0	0	17	18	94.4
Total	49	31	58	17	155	
Producer's accuracy (%)	93.9	83.9	94.8	100		

Overall classification accuracy=92.9%

Overall Kappa=0.899

[a] Mixed aquatic=mixed aquatic vegetation

[b] Woody=mixed woody vegetation

Bird satellite (DigitalGlobe, Inc.[1] Longmont, Colorado). The multispectral imagery consisted of the blue (450 to 520-nm), green (520 to 600-nm), red (630 to 690-nm), and near-infrared (760 to 900-nm) bands. The panchromatic imagery had sensitivity from 450 to 900-nm. The imagery was atmospherically, radiometrically, and geometrically corrected and rectified to the World Geodetic Survey 1984 (WGS 84) datum and universal transverse Mercator (UTM zone 15 North) coordinate system. For this study, we evaluated two three-band composite images (color-infrared and normal color) and a four-band composite image for mapping giant salvinia. The color-infrared composite consisted of the green, red, and near-infrared bands, while the normal color composite consisted of the blue, green, and red bands. The four-band composite image consisted of the blue, green, red, and near-infrared bands. The four-band composite image was evaluated to determine if it may yield better accuracy than the standard three-band color-infrared and normal color composites for mapping giant salvinia.

A subset image that covered the giant salvinia study site was extracted from the multispectral satellite image. It was registered to the panchromatic image of the study site. The positional accuracy of the panchromatic imagery had been improved by rectifying it to ground control points collected with a differential global positioning system (GPS, Trimble Pathfinder Pro XRS, Trimble Navigation Ltd., Sunnyvale, California) having sub-meter accuracy. The ERDAS (Earth Resource Data Analysis System) Imagine software (version 8.7; Leica Geosystems LLC., Atlanta, Georgia) was employed for the image rectification and registration (Erdas, Inc. 2002).

The three composite images of the study site were subjected to an unsupervised classification using the Iterative Self Organizing Data Analysis (ISODATA) technique of the ERDAS Imagine software (Erdas, Inc. 2002). Researchers have widely employed this unsupervised classification procedure to assign pixels to spectral clusters. The ISODATA technique uses minimum spectral distance to assign a cluster for each selected pixel. It begins with arbitrary cluster means, and each time the clustering repeats, the means of the classes are shifted. The new cluster means are used for each iteration.

Initially, the unsupervised classification of the three composite images created 75 classes. The 75 classes were eventually merged into four classes. The four classes consisted of giant salvinia, mixed aquatic vegetation, mixed woody vegetation, and water. The mixed woody and aquatic vegetation consisted of the species mentioned above.

For accuracy assessment, 155 points were assigned to the classes in a stratified random pattern using Erdas Imagine software (Erdas, Inc. 2002). The geographic coordinates of the points were determined and the differential GPS was used to navigate to the points in ground truthing. The stratified random pattern is based on the areas of the classes. For smaller classes a minimum of ten points can be used, regardless of the

[1] Trade names are included for information purposes only and do not imply endorsement of or a preference for the product listed by the United States Department of Agriculture.

Table 2 An error matrix for the unsupervised classification data and ground data for the normal color QuickBird satellite image of the giant salvinia study site on Toledo Bend Reservoir in east Texas

Classified category	Actual category				Total	User's accuracy (%)
	Giant salvinia	Mixed aquatic	Woody	Water		
Giant salvinia	43	3	2	0	48	89.6
Mixed aquatic[a]	5	25	3	0	33	75.8
Woody[b]	0	3	51	0	54	94.4
Water	1	0	2	17	20	85.0
Total	49	31	58	17	155	
Producer's accuracy (%)	87.8	80.6	87.9	100		

Overall classification accuracy=87.7%

Overall Kappa=0.829

[a] Mixed aquatic=mixed aquatic vegetation

[b] Woody=mixed woody vegetation

size of the area. Thus, the number of points in the classes is not proportional to their actual size on the ground. The overall accuracy, producer's accuracy, user's accuracy, and overall kappa coefficient were calculated for each site (Congalton and Green 1999). Overall accuracy is the division of the total number of correct points by the total number of points. The producer's accuracy is the total number of correct points in a category divided by the number of points of that category as derived from the reference data (ground truthing). The user's accuracy is the total number of correct points in a category divided by the total number of points of that category as derived from the classification data or map data. The overall kappa coefficient indicates how well the classification results agree with the reference data.

Results and discussion

The color-infrared composite satellite image of the study site is shown in Fig. 1a. Mature giant salvinia populations have a whitish-pink tone, while less dense, immature populations have a blue-pink image tone. Mixed woody vegetation has a dark red to reddish-brown response, mixed aquatic vegetation has a variable lighter red to reddish-pink tones, and water has a dark blue to black color.

The whitish-pink to blue-pink image of giant salvinia was attributed to its relatively high visible green reflectance (Everitt et al. 2002). The darker image tones of mixed woody species was probably due to their generally low to moderate visible

Table 3 An error matrix for the unsupervised classification data and ground data for the four-band composite QuickBird satellite image of the giant salvinia study site on Toledo Bend Reservoir in east Texas

Classified category	Actual category				Total	User's accuracy (%)
	Giant salvinia	Mixed aquatic	Woody	Water		
Giant salvinia	43	3	0	0	46	93.5
Mixed aquatic[a]	3	26	4	0	33	78.8
Woody[b]	0	2	54	0	56	96.4
Water	3	0	0	17	20	85.0
Total	49	31	58	17	155	
Producer's Accuracy (%)	87.8	83.9	93.1	100		

Overall classification accuracy=90.3%

Overall Kappa=0.865

[a] Mixed aquatic=mixed aquatic vegetation

[b] Woody=mixed woody vegetation

reflectance (Everitt et al. 1987). Mixed aquatic species including alligator weed, smartweed, and pennywort also have lower visible reflectance than giant salvinia giving them various light red and pinkish-red image tones in the color-infrared image (Everitt et al. 2002).

The unsupervised classification of the color-infrared satellite image of the study site is shown in Fig. 1b. The size of the study area was 94.1 ha. Color codes and respective areas/percentages for the various surface types are: pink=giant salvinia (33.2 ha, 35.3%); red=mixed woody vegetation (34.4 ha, 36.6%); green=mixed aquatic vegetation (21.1 ha, 22.4%); and blue=water (5.4 ha, 5.7%). A qualitative comparison of the classified map to the satellite image suggests that the unsupervised classification successfully identified giant salvinia and most of the other surface types.

The error matrix showing comparison of the classified data with the ground data for the 155 observations from the unsupervised classification of the color-infrared satellite image is shown in Table 1. The overall accuracy was 92.9%, indicating that 92.9% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of the individual classes ranged from 83.9% for mixed aquatic vegetation to 100% for water. The user's accuracy ranged from 86.7% for mixed aquatic vegetation to 96.5% for mixed woody vegetation. Giant salvinia had a producer's accuracy of 93.9% and a user's accuracy of 92%. The minor errors in the producer's and user's accuracy of giant salvinia were primarily due to its confusion with mixed aquatic vegetation. Thomlinson et al. (1999) set a target of an overall accuracy of 85% with no class less than 70%. Based on these guidelines, the overall accuracy was excellent, as well as both the producer's and user's accuracies of giant salvinia. Another accuracy measure, the kappa estimate, was 0.899, indicating the classification has achieved an accuracy that is 89.9% better than would be expected from the random assignment of pixels to categories.

Table 2 shows an error matrix by comparison of the classified data with the ground data for the 155 observations from the unsupervised classification of the normal color satellite image (satellite image and computer classification not shown). The overall accuracy was 87.7%. Giant salvinia had a producer's accuracy of 87.8% and user's accuracy of 89.6%, both considered very good. The kappa estimate was 0.829.

Table 3 shows the error matrix comparing the classified data with ground data from the unsupervised classification of the four-band composite image (satellite image and computer classification not shown). The overall accuracy was 90.3%. Giant salvinia had a producer's accuracy of 87.8% and a user's accuracy of 93.5%. The relatively lower user's accuracy of mixed aquatic vegetation was due to its confusion with giant salvinia and mixed woody vegetation. The kappa estimate was 0.865.

Conclusions

Results from this study showed that QuickBird satellite imagery combined with image analysis can be used for distinguishing giant salvinia in an east Texas reservoir. Accuracy assessments performed on unsupervised classification maps of the color-infrared, normal color, and four-band composite images had producer's and user's accuracies ranging from 87.8 to 93.5%. All three composite images did an excellent job in distinguishing giant salvinia and were deemed equal. The accuracy assessment data presented in this study are comparable to those obtained for higher resolution color-infrared photography of giant salvinia in southeast Texas (Everitt et al. 2002). Everitt et al. (2002) reported that giant salvinia had a pink image tone as compared to the whitish-pink or blue-pink color on the color-infrared satellite imagery in this study. Differences in image tones may be due to the chemical emulsions of the aerial photographic film versus the electronic coding of the satellite imagery, as well as differences in plant phenology. The ability to distinguish giant salvinia on satellite imagery is useful to wetland resource managers who are interested in mapping infestations over large and inaccessible areas.

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